FIELD OF VIEW DIRECTLY BEHIND LARGE TRUCKS AND BUSES

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This paper summarizes the research performed during a study for the National Highway Traffic Safety Administration of the U.S. Department of Transportation. The blind area directly behind small trucks, multipurpose vehicles, large trucks, and buses was investigated to determine the rear-view information that a driver needs to reduce accident risk for various driving situations. Accident data, driver evaluation of risk and information needs, and vehicle use patterns obtained from riding with truck and bus drivers were used to determine that the blind area increases driving risk most for backing, turning (including making lane changes, merging, and entering and exiting expressways), slowing, and stopping, in that order. Several state-of-the-art techniques have the potential to eliminate the blind area behind various vehicles. Based on a survey of manufacturer information and devices, a comparison was made of the alternative techniques by criteria such as potential effectiveness in the operational environment, cost maintainability, and availability. It was concluded that the use of an effective rear-vision system would be beneficial for several of the types of vehicles considered. The techniques that appear most promising are television systems, closing rate sensors (doppler radar), and proximity (acoustic) sensors. The primary recommendation was to perform selected tests and demonstrations of readily available existing systems on certain vehicles and under certain conditions to supplement the system analysis of the study with experimental data.

•A SURVEY of the literature showed that vehicle rear vision had not been related to accidents in any quantitative manner (1). The Road Research Laboratory (11) reported that a large number of accidents occur while vehicles are turning and that this may be due to unfulfilled driver information needs concerning the rear blind areas (inadequate or unused mirrors). The key problem with motor vehicle rear vision is field of view (6). A polling of experts indicated that rear vision was second only to brakes as an area for cost-effective motor vehicle safety (6). Numerous authorities agree that motor vehicle rear vision needs to be improved (3, 4, 5, 9, 10). Whitmer and von Kampen (12) indicate that improvements in the following broad areas will reduce truck and bus collisions: (a) better vision and improved rear-view systems, (b) improved vehicle capability to perform evasive tactics, and (c) vehicle design to reduce driver fatigue. Connolly (3) points out that most vehicular accidents are being reduced effectively except for sideswipes and rear-end collisions where rear vision plays an important role. Several researchers agree that the rear-vision information requirements are more stringent for trucks and buses than for passenger cars (especially for merging and lane changing because of the larger gaps required) but that the means of satisfying these requirements are more limited and less satisfactory than for cars. Something better than original equipment mirrors is badly needed (6, 7, 8, 10). Combined mirror systems

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(plane and convex exterior side mirrors for each side) will eliminate the truck and bus side blind areas to the rear of the driver if care is used in selecting the proper mirror sizes, curvature, and location based on the geometry of the vehicle in question. What is now needed is to provide information regarding the blind area directly behind the vehicle. Periscopes can do so for cars but cannot readily do so for trucks.

SCOPE

This paper outlines some areas where state-of-the-art systems can reduce specific accidents related to the restricted field of view behind large trucks and buses. It briefly considers the accident problem attributable, either directly or indirectly, to the lack of information about events in the rear blind area. The scope and magnitude of the accident problem can be used to determine whether the expenses of developing and implementing new on-vehicle systems can be justified. The paper discusses the evaluation of vision information elements and risks. Three types of analyses are presented:

1. A determination of vehicle exposure by maneuver,
2. Driver ranking of maneuver risk, and
3. Driver indication of the type of rearward information desired and when this information should be provided.

Finally, several technologies are evaluated on the basis of their current performance and satisfaction of information requirements.

ACCIDENT SITUATION

General

Annual statistics provided by the National Safety Council and the Federal Highway Administration provide the safety community with insights into the national accident picture for trucks and buses. The accident rates for all trucks indicate their underinvolvement in accidents on the basis of their numbers and annual vehicle miles (kilometers) of travel. Articulated vehicles (truck-tractor and semitrailer combination) and commercial buses are overrepresented in the accident statistics (13, 14, 15). Articulated trucks represent 5.4 percent of the registered truck population and put on 18.7 percent of truck distance traveled but are involved in a disproportionate 21 percent of all truck accidents and 36 percent of all fatal truck accidents. Articulated trucks are harder to maneuver, slower to accelerate, slower to bring to a stop, require a sizable gap in lane changing, and have a more severe rear-vision problem than small trucks, which have a rear window and rearview mirror. The average articulated truck puts on 41,903 miles/year (67 044.8 km/year) compared with the 9,807 miles/year (15 691.2 km/year) for the single-unit truck and puts on the most miles (kilometers) per year of all the vehicles for which data are gathered.

The school bus represents 0.3 percent of the total registered vehicles, puts on 0.2 percent of the total vehicle distance traveled, and is involved in 0.2 percent of all vehicle accidents and 0.2 percent of all fatal vehicle accidents. The commercial buses represent 0.1 percent of the total vehicle population and put on about 0.26 percent of the total vehicle distance traveled but are involved in 0.6 percent of all vehicle accidents and 0.5 percent of all fatal vehicle accidents. It should be noted that the commercial bus is the only one of the truck and bus categories considered where more than half (61.5 percent) of the miles (kilometers) of travel are on crowded urban streets. The commercial bus is second to the articulated truck in putting on the highest annual distance traveled [32,591 miles/year (52 721.6 km/year)].

Rear Vision

An analysis of truck accidents was made based on 1969 Bureau of Motor Carrier Safety data (16). Table 1 gives a summary of some of the findings of this analysis. This summary indicates that lack of rear vision was probably a factor in slightly more than 30 percent of the truck accidents. It was estimated that between 430,000 and 900,000 annual truck accidents include lack of information regarding the blind area directly behind the vehicle as one of a number of diverse causes. It was estimated that 18 percent of the 2.8 million truck accidents in 1970 and the resulting 13,000 fatalities and 379,000 injuries could have been prevented with a system providing rear-blind-area information. Using figures of $2,109/truck/property-damage accident, $1,400/injury, and $54,000/fatality, Reiss, Lunenfeld, and Morton (17, chapter 6) calculated that $50/year/truck (based on a 10-year truck lifetime) could be expended to install and maintain a rear-blind-area information system and costs would equal savings.

On the basis of producing enough systems to permit large-scale mass production (hence low unit costs), the rear-vision systems can be justified for trucks alone but not for buses alone. A bus system, to be cost effective, would have to be identical to the truck system.

INFORMATION ELEMENTS AND RISKS IN VEHICLE OPERATIONS

Driving has been characterized as a complex sensory-motor task in which the driver must constantly scan the internal environment of the vehicle and the external environment of the road and traffic and obtain information from many sources to maintain an appreciation of a constantly changing situation. From this information and other knowledge and skills, the driver judges, predicts, and estimates to maintain an area of safe travel relative to his or her vehicle and other fixed and moving elements in the environment.

Visual information accounts for 90 percent of all information received. Anything that leads to blockage of the visual information can, in turn, lead to missed information and driving errors. Because driving error has been shown to lead to the majority of accidents, the driver must be provided with the information needed for a clear field of view in all directions at all times.

With current vehicle configurations and rear-vision devices, a blind area exists to the rear of vehicles. This blind area is particularly severe on large vehicles, such as vans, straight-body trucks, articulated vehicles, buses, and motor homes, where vehicle configuration, the general lack or blockage of a rear window, and the inability of conventional mirror systems to provide a clear rear field of view lead to a situation of little or no information received from the area directly behind the vehicle.

The need for information from the rear field of view can be defined and evaluated in relation to the vehicle operations for the various categories of vans, trucks, buses, and motor homes representative of the overall large vehicle population. The problem can be structured by identifying information needs associated with various vehicle operations and by assessing the criticality of increased accident risk if these needs are not satisfied.

The scope and magnitude of the accident problem were developed to provide a framework for the problem and an upper limit to potential accident involvement due to non-receipt of rearward information. Rear-field-of-vision information elements and risks were considered and the primary determinations were

1. Vehicle operations profile,
2. Driver estimation of risks, and
3. Information needed for driver decision.

Several field-data-gathering activities were developed to find out what the driver is doing and what the professional driver considers to be problems relating to rear vision.

Vehicle Exposure by Maneuver

The researchers' riding on 6 types of vehicles (delivery van, straight-body truck, tractor-trailer combination, school bus, intercity bus, and motor home) while the drivers performed their typical missions led to 3 findings.

1. Backing is the least performed maneuver (between 0.1 and 5 percent of total maneuvers). The straight-body truck backed the most, and the school bus backed the least. The usage pattern of larger trucks indicated that most backing occurs during loading and unloading.
2. Slowing and stopping represented between 37 and 57 percent of all maneuvers. The van and the intercity bus performed this maneuver the least, and the straight-body truck, semitrailer, and school bus performed it the most.
3. Turning (lane changing, passing, merging) was performed as much as 63 percent by the intercity bus and as little as 40 percent for the semitrailer. It represents the most frequent maneuver category (as well as the highest rear-blind-area accident category).

The data collected included those on operational environment, time in the environment, and maneuver performed (Tables 2, 3, and 4). All of this information was pulled together into a vehicle use pattern for each vehicle. Analysis of the use patterns for semitrailer (Table 5) indicates that, for the observation period, backing up representd about 4 percent, lane changing represented about 22 percent, and slowing and stopping represented about 53 percent of all maneuvers. Daily operations then were combined with the drivers' perceptions of risks and evaluation of information needs.

Driver Estimation of Risk

A survey was developed to estimate how professional drivers perceived risks for the various maneuvers and environments. The respondents were required to rate each maneuver in each environment on a 7-point scale from least risk to greatest risk (Figure 1). The survey was designed to be self-administered. It was distributed on a limited basis to those operators who assisted in vehicle use data collection. Fifty responses were obtained.

Driving Experience

The driving experience of the sample survey is as follows:

Group	Number in Sample	Mean Years of Professional Experience	Standard Deviation
Bus drivers	28	11.3	5.5
Truck drivers	22	23.5	8.9
Combined	50	16.6	9.4

The data in this tabulation show that the bus driver sample had about half the driving experience that the truck drivers had. The drivers in the sample, then, were quite experienced and represented a group of professionals whose ratings would yield the desired ratings of risk required.

Table 1. Truck accident analysis (16).

Category	Fatalities		Injuries		Accidents	
	Number	Percent	Number	Percent	Number	Percent
Maneuvers involving rear view						
Backing	6	0.4	169	0.8	1,220	3.1
Moving straight ahead, slowing, or stopping[a]	202	13.4	3,711	18.8	4,754	12.1
Being stopped in traffic[a]	6	0.4	58	0.3	123	0.3
Passing, turning, and lane changing	319	21.0	3,545	18.1	1,659	17.0
All other maneuvers[b]	964	64.8	12,199	62.0	26,057	67.5
Total	1,497	100.0	19,682	100.0	38,813	100.0

[a]Struck in rear. [b]Includes maneuvers involving accidents such as head-on and sideswipe accidents from opposite direction.

Table 2. Vehicle exposure by environment.

Environment	Percentage of Total Operational Time					
	Van	Straight-Body Truck	Semitrailer	School Bus	Intercity Bus	Motor Home
Urban						
Streets	0	6.0	14.0	0	0.7	0
Arterials	0	42.0	23.0	12.0	7.0	0.4
Freeways	0	14.0	28.0	0	12.3	7.2
Suburban						
Streets	7.0	0.3	0.2	14.0	0	1.0
Arterials	68.0	14.0	9.0	44.0	0	5.0
Freeways	7.0	11.1	14.0	4.0	24.0	21.4
Rural						
Roads	0	0	0	0	0	0
Arterials	0	0.3	2.0	13.0	0	42.0
Freeways	0	1.0	0	0	50.0	16.0
Bridges	0	1.0	5.0	0	2.5	4.0
Tunnels	0	0	0	0	2.5	0
Circles	0	1.0	1.0	0	0	0
Driveways	0	0.2	0	0	0	0
Loading zones	0	5.0	0	0	0	0
Parking areas	18.0	4.0	3.0	13.0	0	3.0
Terminals	0	0.1	0.8	0	1.0	0
Roads with no access control	7.0	6.3	14.2	14.0	0.7	1.0
Roads with partial access control	68.0	56.3	34.0	69.0	7.0	49.4
Roads with full access control	7.0	26.1	42.0	4.0	86.3	42.6

Table 3. Vehicle use by maneuver.

Type of Maneuver	Number of Maneuvers					
	Van	Straight-Body Truck	Semitrailer	School Bus	Intercity Bus	Motor Home
Right turn	36	65	60	14	5	12
Left turn	36	126	60	13	4	16
U-turn	8	6	4	0	1	0
Left lane change	40	103	82	6	132	34
Right lane change	36	134	93	12	130	61
Slowing and stopping	113	587	424	58	194	103
Entering freeway	7	4	6	0	2	10
Exiting freeway	6	5	11	0	0	11
Passing on right	2	0	0	0	0	0
Passing on left	6	6	14	0	60	4
Backing	10	53	31	1	1	2
Merging	8	17	21	2	1	13
Total	308	1,106	806	106	530	266

Table 4. Time involved in maneuvers by vehicle.

Vehicle	Time in Maneuvers (min)	Maneuvers/ Min
Van	115	2.68
Straight-body truck	450	2.46
Semitrailer	364	2.21
School bus	43	2.47
Intercity bus	241	2.19
Motor home	397	0.67

Table 5. Vehicle usage pattern for 55-ft (16.8-m), 4-axle semitrailers.

Environment	Exposure Percentage	Maneuvers/ Min	Number of Maneuvers												
			Right Turn	Left Turn	U-Turn	Right Lane Change	Left Lane Change	Slow or Stop	Enter	Exit	Pass on Right	Pass on Left	Merge	Back Up	Σ
Urban															
Streets	14.0	3.36	23	17	0	16	12	91	1	0	0	0	2	9	171
Arterials	23.0	2.35	18	26	0	20	19	103	2	2	0	2	4	1	197
Freeways	28.0	1.50	2	2	0	25	20	82	1	6	0	5	10	0	153
Suburban															
Streets	0.2	5.49	1	1	0	0	0	2	0	0	0	0	0	0	4
Arterials	9.0	2.44	7	6	0	8	8	47	0	2	0	1	1	0	80
Freeways	14.0	1.18	1	0	0	9	5	37	1	1	0	4	2	0	60
Rural															
Local roads	2.0	1.92	0	1	0	1	1	11	0	0	0	0	0	0	14
Freeways	0.0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other on road	6.0	2.88	1	2	0	13	17	25	1	0	0	2	2	0	63
Off road	3.8	4.63	7	5	4	1	0	26	0	0	0	0	0	21	64
Total	100.0	2.21	60	60	4	93	82	424	6	11	0	14	21	31	806

Average Distance Driven

The drivers in the sample were surveyed to ascertain the average yearly distance driven. Bus drivers drove an average of approximately 17,000 miles/year (27 200 km/year); the truckers drove an average of 44,000 miles/year (70 400 km/year). The bus driver sample was drawn from line bus drivers as well as intercity bus drivers, and this might account for the somewhat lower figure for bus driver distance driven. The combined mean figure for distance driven, 28,900 miles (46 240 km) with a variability of 19,900 miles (31 840 km), indicates that the sample did have considerable yearly exposure.

Driver Perception of Risk

The subjects' responses to 29 maneuver-environmental categories were summarized into a set of frequency distributions for each subgroup. The scale of risk used is as follows:

Category	Rating	Category	Rating
Least risk	1	Some risk	4
Very little risk	2	A risk	5
		Great risk	6
Minor risk	3	Greatest risk	7

Drivers rated the risk of various maneuvers arising from lack of information on the rear blind area. The general category rated as having highest risk was backing, and backing onto the street or road from an off-the-road area was rated as having the greatest risk within this category (6.7). Next in order of risk were making U-turns (5.3) and slowing and stopping on suburban or rural roads (4.9). Driving in lane was considered to have the least risk for all environments (1.6). The professional drivers did not consider the freeway environment as a great risk and felt that there was some risk (4.0 or greater) with more than half the categories rated.

The total sample responding to the driver survey was divided into 2 sets of responses: those from truck drivers and those from bus drivers. The perceived accident risks of each of these subgroups were compared. Table 6 gives a summary of the responses from the truck drivers.

The bus drivers consistently rated the accident risks arising from the rear blind area higher than the truck drivers did in the high-risk maneuver and environment categories (backing, U-turns, slowing and stopping, etc.). The bus drivers rated 16 categories at 4.0 or greater (actually 4.9 or greater); the truck drivers rated only 11 categories (fewer than half the categories) at 4.0 or greater, and they rated only 8 at 4.7 or greater.

Both the bus and truck drivers rated the backing maneuver as the greatest risk. The bus drivers considered U-turns to be much greater risks than the truck drivers did. This may be because bus drivers rarely perform U-turns.

The bus drivers also rated certain aspects of freeway driving—entering and exiting onto freeways, pulling onto shoulders, and merging onto local roads from freeways—as high risks, and the truck drivers did not. This finding, however, may be because line bus operators (who usually do not drive on freeways) made up a large portion of the bus driver sample.

It is interesting to note from these findings, which, it should be clearly pointed out, were derived from a small restricted sample of drivers, that bus and truck drivers perceive somewhat differently accident risks associated with the rear blind area. This may have some bearing on when and under what circumstances these classes of drivers would use a device designed to aid them in gathering rear-vision information. It also must be noted that trucks are more likely to be equipped with right-side "West Coast"

Figure 1. Survey format.

TRUCK AND BUS REAR VISION SURVEY

1. WHAT KIND OF A VEHICLE DO YOU USUALLY DRIVE PROFESSIONALLY? tractor trailer
2. HOW MANY YEARS HAVE YOU BEEN DRIVING PROFESSIONALLY? 11
3. HOW MANY MILES A YEAR DO YOU USUALLY LOG? approx. 30,000

AS A PROFESSIONAL DRIVER, PLEASE RATE HOW THE BLIND SPOT DIRECTLY BEHIND YOUR VEHICLE INCREASES THE RISK OF AN ACCIDENT FOR EACH DRIVING SITUATION. (CHECK ONE BOX FOR EACH SITUATION.)

4. IN YOUR OPINION, ON CITY STREETS, HOW MUCH OF AN ACCIDENT RISK DOES THE REAR BLIND SPOT CREATE WHEN YOU ARE:

	LEAST RISK	VERY LITTLE RISK	MINOR RISK	SOME RISK	A RISK	GREAT RISK	GREATEST RISK
A. DRIVING IN LANE	✓						
B. MAKING A RIGHT TURN			✓				
C. MAKING A LEFT TURN	✓						
D. MAKING A U TURN illegal							
E. CHANGING TO LEFT LANE	✓						
F. CHANGING TO RIGHT LANE			✓				
G. SLOWING AND STOPPING				✓			
H. BACKING ON THE STREET						✓	
I. BACKING IN FROM STREET INTO DOCK OR LOADING AREA						✓	
J. OFF-STREET PARKING OR DOCKING						✓	
K. BACKING ONTO STREET FROM LOADING AREA OR ALLEY						✓	

Table 6. Perception of risk by truck drivers.

Category	Maneuver	Environment	Rating[a] Mean	Rating[a] Standard Deviation
Backing	Backing onto street from loading area or alley	City streets	6.4	0.6
	Backing onto road from parking lot or rest area	Suburban or rural roads	6.2	0.6
	Backing	City streets	5.9	0.9
		Suburban or rural roads	5.6	0.9
	Backing into dock or loading area	City streets	5.4	1.2
		Suburban or rural roads	5.4	0.9
Turning	Making a U-turn	City streets	4.8	1.8
		Suburban or rural roads	4.7	1.7
	Changing to right lane	City streets	3.7	1.5
		Suburban or rural roads	4.0	1.5
		Urban and rural roads	3.6	1.6
	Merging from freeway onto local or service roads	Urban and rural freeways	4.0	1.6
	Making a right turn	City streets	3.5	1.5
		Suburban or rural roads	3.2	1.4
	Off-street parking or docking	City streets	3.5	2.0
	Parking or docking in parking lot or rest area	Suburban or rural roads	3.2	1.8
	Pulling onto shoulder	Urban and rural freeways	3.1	1.5
	Entering freeway	Urban and rural freeways	2.7	1.2
	Changing to left lane	City streets	2.7	1.2
		City streets	2.7	1.1
		Suburban or rural roads	2.6	1.0
	Making a left turn	City streets	2.6	1.3
		Suburban or rural roads	2.5	0.9
	Exiting from freeway onto exit ramp	Urban and rural freeways	2.5	1.1
Moving straight ahead	Slowing and stopping	City streets	3.2	1.2
		Suburban or rural roads	4.0	1.5
	Driving in lane	City streets	1.8	1.0
		Suburban or rural roads	1.8	0.7
		Urban and rural freeways	1.7	0.8

Note: Sample size was 22.

[a]Rating of risk is from 1 (least risk) to 7 (greatest risk).

Figure 2. Interview format.

INTERVIEW SCHEDULE

B. INFORMATION NEEDS: WE WOULD LIKE TO KNOW SOME THINGS ABOUT THE REAR VISION INFORMATION YOU FEEL YOU NEED, AND HOW YOU PRESENTLY GET IT.

1. INFORMATION NEEDS: THERE ARE A NUMBER OF TYPES OF INFORMATION ABOUT WHAT IS HAPPENING IN THE REAR BLIND AREA ..... LET ME GIVE YOU SOME EXAMPLES:

- PRESENCE - THERE IS SOMETHING IN THE REAR AREA.
- IDENTIFICATION - WHAT THAT SOMETHING IS, E.G. A CAR, A TRUCK, A PEDESTRIAN.
- DISTANCE - HOW FAR THE OBJECT OR VEHICLE OR PERSON IS FROM YOUR REAR BUMPER.
- RELATIVE MOTION - WHAT THE OBJECT OR VEHICLE OR PERSON IS DOING, E.G. A VEHICLE COMING UP ON YOUR TAIL, A STATIONARY OBJECT LIKE A FENCE POST, A PERSON WALKING BEHIND THE VEHICLE.
- INTENTIONS - WHAT THE OBJECT OR PERSON OR VEHICLE IS GOING TO DO, E.G. IS THE VEHICLE CHANGING LANES? IS THE PERSON GOING TO STOP? IS THE OBJECT IMMOVABLE?
- GIVEN THESE EXAMPLES, WE WOULD LIKE YOU TO TELL US WHICH OF THESE TYPES OF INFORMATION YOU FEEL YOU NEED, IN ORDER OF IMPORTANCE, FOR THE FOLLOWING MANEUVERS:

A. DRIVING IN LANE. ______
B. MAKING A RIGHT TURN. ______
C. MAKING A LEFT TURN. ______
D. MAKING A U TURN. ______
E. CHANGING TO LEFT LANE. ______
F. CHANGING TO RIGHT LANE. ______
G. SLOWING OR STOPPING. ______
H. TAKING AN ENTRANCE RAMP. ______
I. TAKING AN EXIT RAMP. ______
J. BACKING ON THE ROAD. ______

Table 7. Driver information needs by maneuver.

Maneuver	Van	Straight-Body Truck	Semitrailer	School Bus	Intercity Bus	Motor Home
Driving in lane	Presence, speed, distance	Presence, distance	Relative motion, identification, presence, distance	Presence, distance, relative motion	Presence	Presence, distance
Right turn	Presence, identification	Presence, distance	Relative motion, identification, presence, distance	Presence, distance, relative motion	Presence	Presence, distance
Left turn	Presence, identification	Presence, distance	Relative motion, identification, presence, distance	Presence, distance, relative motion	Presence	Presence, distance
U-turn	Presence, identification	Presence, distance	Illegal	Illegal	Presence	Presence, distance
Left lane change	Presence	Presence, distance	No problem	Presence, distance, relative motion	Presence	Presence, distance, relative motion
Right lane change	Presence, speed, distance	Presence, distance	No problem	Presence, distance, relative motion	Presence	Presence, distance, relative motion
Slowing or stopping	Presence, distance, relative motion	Presence, distance	Relative motion, identification, presence, distance	Presence, distance,	Presence	Presence, distance, relative motion
Taking an entrance ramp	No problem	Presence, distance	No problem	Presence, distance	Presence	Presence
Taking an exit ramp	Presence, distance	Presence, distance	No problem	Presence, distance	Presence	Presence
Backing on roadway	Identification, relative motion	Presence, distance	Relative motion, identification, presence, distance	Identification, presence, distance, relative motion	Presence	Presence, distance, identification, relative motion
Backing into dock	No problem	Presence	Relative motion, identification, presence, distance	Presence, relative motion	Presence	Presence, distance, identification, relative motion
Backing onto road from loading zone	Relative motion, movement	Presence, distance	Relative motion, identification, presence, distance	Presence, relative motion	Presence	Presence, distance, identification, relative motion

mirrors and convex mirrors than are the average line buses. Thus, information gathering may be somewhat easier for truck drivers than for bus drivers.

Driver Evaluation of Information Needs

The driver survey was augmented by a number of in-depth personal interviews (Figure 2). The drivers of the 6 types of vehicles indicated that 5 classes of rear-blind-area information were desired (presence of a vehicle or object, distance, relative motion, identification, and intention). The data given in Table 7 indicate that the minimum information that a rear-vision device should provide is presence of a vehicle and how far away it is. Relative motion (how fast a vehicle is traveling in relation to the driver in question) was next in importance. The information needs categories with the least number of responses were identification of other vehicles and intentions. For backing operations, drivers need to know the presence of an obstruction in the rear blind area and how far away it is before starting to move backward. For forward operations, to prevent turning accidents, drivers also should know something about the closure rate between vehicles and intentions. For forward operations, to perform an evasive maneuver to prevent a rear-end collision, drivers should know presence, distance, relative motion, and intentions.

The information requirements for forward operations are greater because drivers divide their information gathering between the road ahead and the road behind. Because the rate of speed and changes in speed are considerable in forward operations, drivers are under stringent time pressures to gather information and make decisions.

EVALUATION OF SYSTEMS

After we defined rear-vision information needs, we investigated whether any promising techniques existed that would provide the required information. Table 8 gives a summary of the systems examined. Visual, intrusion, and proximity warning systems were evaluated.

Table 8. Evaluation of systems.

					Information Provided					
							Relative Motion			
System	Availability	Mode	Types of Vehicles	Operation	Presence	Relative Distance	Closing	Lateral	Intentions	Indentification
Visual warning										
Closed-circuit television	Operational	System	All	Forward and backward	Yes	Yes	Yes	Yes	Yes	Yes
Periscope	Test	System	Van	Forward and backward	Yes	Yes	Yes	Yes	Yes	Yes
Fiber optics	Not available	Device	Van	Backward	Yes	Yes	Yes	Yes	Yes	Yes
Intrusion warning, doppler radar	Test	System	All	Forward and backward	Yes	No	Yes	No	No	No
Proximity warning										
Acoustic										
Passive	Test	System	Van[a]	Forward	Yes	No	No	No	No	No
Active	Test	System	All	Backward	Yes	Yes	Yes	No	No	No
Laser	Not available	Device	All	Backward	Yes	No	Yes	Yes	No	No

System	Environmental Limits	Maintenance	Reliability	Cost	Problems
Visual warning					
Closed-circut television	Fair	Medium to heavy	Fair	Medium	Limited light level, poor visibility (fog, snow, road film)
Periscope	Fair	Low	Good	Low	Limited light level, poor visibility (fog, snow, road film)
Fiber optics	Fair	Unknown	Unknown	High	Limited light level, poor visibility (fog, snow, road film)
Intrusion warning, doppler radar	Good	Low	Good	Low	Requires motion
Proximity warning					
Acoustic					
Passive	Poor	Unknown	Unknown	Medium	Road noise
Active	Good	Unknown	Unknown	Medium	Operates for backing only
Laser	Fair	Unknown	Unknown	Medium	Range is limited by power

[a]Questionable.

Mode of Use

Some of the systems investigated appeared suitable for use in backing operations only. The limitation in all of these cases (periscope, acoustic and optical proximity sensors) was that of range. In the case of the periscope the range limitation was not inherent to the device but resulted from mechanical constraints that limit the field of view. The passive acoustic system was considered for possible use in forward operations only because of the 35-mph (56-km/h) minimum velocity required of the target vehicle. Doppler radar units require relative motion. When a vehicle is stopped it will detect only moving objects. All other systems or devices were judged to be usable in either forward or backing operations.

Information Provided

Presence

The minimum requirement that must be satisfied is an indication of the presence of an object within the field of view. The time delay between intrusion of the object and indication of its presence to the user must be short compared to the acceptable response time by the vehicle operator. Generally a few tenths of a second is presumed to be adequate for indicating devices. All of those considered appear capable of meeting this criterion.

Relative Distance or Range

An indication of the spatial relationship between the host vehicle and the intruding object provides the driver with additional information to guide his or her response to new traffic situations. Of the nonvisual systems, only the acoustic equipment provides a continuous indication of range.

Relative Motion

All but the passive acoustic system have the inherent capability for indicating relative velocity between intruding objects and the host vehicle. However, only the visual and laser systems have the directional resolution necessary to indicate lateral motion within the field of view.

Intentions

The response of the driver to a new traffic situation frequently depends on his or her ability to estimate the future course of an overtaking vehicle and the intentions of its operator. Only those devices that provide the user with a visual image of the rear field of view were judged to be satisfactory.

Identification

A detailed identification of objects within the rear field of view of the host vehicle affords additional information for the driver who is reacting to their presence. This information is particularly useful in backing operations (dock versus object). Only the visual systems provide this level of detail.

Information Needs for Specific Maneuvers

In evaluating the information required the systems must be compared on the basis of satisfying the information needs of the specific maneuvers of backing, turning, and slowing and stopping.

The backing mode was rated by the drivers as the highest risk. It represents about 4 percent of the vehicle maneuvers (excluding going straight ahead as a maneuver), about 10 percent of rear-vision-related accidents and about 3 percent of all truck accidents. It happens most frequently with trucks striking cars, trucks, pedestrians and buses (in that order). The primary information need is presence within a given envelope. If the vehicle is at rest prior to backing, the system display will let the driver make a "go" or "no-go" decision. If it is "no-go," the driver should get out and look.

The doppler radar requires a speed of 0.4 mph (0.64 km/h) to function. When backing has been started, it displays the presence of an object, human being, or vehicle within a 30-ft (9-m) envelope behind the vehicle as a "no-go" red light. This is the simplest and least expensive means of resolving the backing problem for the articulated vehicles and medium-duty cargo trucks that do not have rear windows.

The closed-circuit-television system mounted near the roof line of the rear of the vehicle will display on a screen the presence, relative distance, relative motion, identity, and intentions of something within its field of view. This would cover from 1,000 ft (305 m) for a vehicle to perhaps 300 ft (91 m) for an individual. If a fish-eye lens is used, the field will cover the back surface of the vehicle but will introduce distortion that will make the determination of relative distance and relative motion more difficult. Depending on the angle of the camera, the use of a lens that does not have as wide an angle might produce a small blind area at the back surface of the vehicle. Placing the television sensor on the rear surface with the non-wide-angle lens would eliminate the blind spot but possibly would not provide the frame of reference necessary for judging relative distance and motion. Trying the system out on the vehicle would enable the location and lens trade-off to be made quickly. Although the less expensive closed-circuit television systems cost about $200 to $300, a price of $50 has been suggested as feasible. These less-expensive systems would have to be tested to determine whether they will meet the operational criteria. One manufacturer has indicated that its off-the-shelf system, which has been designed for bus operation, costs $700 (with a $56 vidicon tube replacement cost). It is assumed that this could be reduced considerably if the units are mass-produced.

The best all-around system for backing operations only seems to be the Ultrasonic (active acoustic) system. It has been estimated to cost less than $100 in mass production, and the display contains presence and exact distance (and, through change in distance, relative motion) information. It functions much as a Fathometer on a ship and displays through the use of a moving dot on a calibrated dial the presence within 0 to 25 ft (0 to 7.6 m) of an object, dock, vehicle, or individual. Unfortunately the current system will not work in forward operations because its range of 35 ft (11 m) is less than that required to detect presence in this mode. It might be considered if a hybrid system or a backing-only system was acceptable.

The periscope is not discussed in detail because no existing periscope system is amenable to the articulated vehicle or the 28-ft (8.5-m) medium-duty, straight-body truck. Such a system is technically possible, and should one be developed it would probably be the best all-around choice for backing operations. Because it would have to be located near vehicle floor level (to pick up a small object or child close to the ground), it probably would not provide adequate information in forward operations.

The turning category, which includes right and left turns and U-turns, has been used to group other maneuvers such as lane changes, passing, exiting and entering the traveled way, and merging. It is rated by the drivers as having the highest risk after backing. Turning accidents occur most frequently between trucks and cars and then with multiple trucks.

Turning is not as frequent as slowing and stopping but occurs about 40 percent of the time (not considering going straight ahead) and represents more than 50 percent of the rear-vision-related accidents and almost 20 percent of all truck accidents. A signifi-

cant number of these accidents can be prevented, as with backing, by the driver's not performing the maneuver if his or her rear-information systems (including plane and convex side mirrors) convey the information that a high accident potential exists. Ideally, to prevent these accidents the driver should know closing rates (positive and negative) and other possible information concerning the other drivers (or pedestrians), presence, identification, relative distance, and intentions (turn signal blinking). This is fully provided by an optical system only, and the only system providing this for vehicles longer than a van is closed-circuit television.

Drivers probably can be trained to use their combined side mirror systems plus a "go" or "no-go" presence within a general area display to gain enough information to prevent some portion of the rear-vision-related turning accidents. Doppler radar then is also acceptable. An illustration of its inability to be as effective as television is the urban bus line driver in congested city traffic where the "no-go" light probably would be ignored because it would be on almost all of the time.

Slowing and stopping, which represents about 50 to 60 percent of vehicle maneuvers, is the next highest driver-rated risk category. It is the vehicle action in about 37 percent of the truck rear-vision-related accidents and about 12 percent of all truck accidents. Only those information elements provided by optical systems can give drivers enough information to prevent their being struck in the rear. In addition to being able to digest this information in time to take corrective action (driver fatigue enters here), the vehicle would be required to accelerate and change lanes rapidly (all of which is unlikely for large trucks).

Only the television system would seem to give the information required to enable the driver to determine the proper evasive maneuver. A "presence" light that is on at the same time that the car in front starts a panic stop is not adequate.

CONCLUSIONS

Feasibility

From technical, operational, and economic viewpoints, it is feasible to use 1 or more state-of-the-art techniques on various types of trucks and buses to eliminate the blind area behind the vehicle.

Accident Involvement

The blind area directly behind large vehicles increases the risk of accident involvement. One of many diverse causes is unfulfilled driver information needs regarding this area. The magnitude of accidents involving rear-vision factors approaches 900,000 truck and 47,000 bus accidents/year (approximately 32 percent of truck accidents and 21 percent of bus accidents).

Payoff

The annual payoff that can be realized from provision of rear information is greater for trucks than for commercial buses.

Most Promising Technologies

Several of the systems fulfilled well the primary driver information needs of presence, distance, and relative motion. The following satisfied the systems evaluation criteria developed during the study for comparative analysis:

1. Closed-circuit television,
2. Doppler radar, and
3. Active acoustic systems.

Empirical Evidence Is Required

The conclusion that the previously mentioned systems best meet the operational criteria was determined on the basis of analysis of accidents, driver information needs, and manufacturer claims. Testing is required to validate these analytical findings, verify the manufacturer claims, and determine the operational suitability of these systems.

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